Design and Testing of an Intelligent GPS Tracking Loop for Noise Reduction and High Dynamics Applications

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Outline

- Motivation
- Background
  - Fuzzy logic background
  - New design for FLL assisted PLL
- Experimental Setup
- Results
- Conclusions
Motivation

Challenges:
1- Missiles dynamics
2- Signal interference

PLL bandwidth (BW) requirements:
1- Missiles dynamics → wide BW
2- Signal interference → narrow BW
Basic PLL block diagram

Locally generated

Δθ or Δω or both

- Specifies the loop bandwidth
- Can be 1\textsuperscript{st}, 2\textsuperscript{nd}, or 3\textsuperscript{rd} order
- 3\textsuperscript{rd} order filter is chosen because it is sensitive to dynamic jerks
FLL Assisted PLL Classic Design

- 3rd order PLL assisted with 2nd order FLL
- All gains are calculated from the loop bandwidth which is a design parameter

Fuzzy Logic

What Is Fuzzy Logic?

• Quantification of *linguistic information* while allowing for *imprecision*
Fuzzy Frequency Phase lock Loop (FFPLL)

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Membership Functions Design (1/2)

PLL phase discriminator output (deg)

Phase error (deg)

Time (s)

Histogram

Guassian fitting

-BIG  -MED  -SMALL  ZERO  +SMALL  +MED  +BIG
## Membership Functions Design (2/2)

<table>
<thead>
<tr>
<th>Type</th>
<th>Fuzzy Variable</th>
<th>Number of MFs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input(1)</td>
<td>Phase</td>
<td>9</td>
</tr>
<tr>
<td>Input(2)</td>
<td>Frequency</td>
<td>7</td>
</tr>
<tr>
<td>output</td>
<td>NCO Tuning frequency</td>
<td>11</td>
</tr>
</tbody>
</table>

### Membership Function Values

| B: Big, MB: Medium Big, M: Medium, SM: Small Medium, S: Small, Ze: Zero. |

### Table: Membership Functions Design

<table>
<thead>
<tr>
<th>θ down</th>
<th>ω up</th>
<th>-B</th>
<th>-M</th>
<th>-S</th>
<th>Ze</th>
<th>+S</th>
<th>+M</th>
<th>+B</th>
</tr>
</thead>
<tbody>
<tr>
<td>-B</td>
<td>+B</td>
<td>+MB</td>
<td>-M</td>
<td>-M</td>
<td>-M</td>
<td>-MB</td>
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</tr>
<tr>
<td>-MB</td>
<td>+B</td>
<td>+MB</td>
<td>-SM</td>
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<td>-M</td>
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<td>-B</td>
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<tr>
<td>-M</td>
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<td>-MB</td>
<td>-B</td>
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</table>
### Experiment Setup (1/2)

#### GPS H/W simulator
**Spirent GSS7700**

#### National Instrument
**RF Front End**

#### Post processing

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
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<tbody>
<tr>
<td>Sampling frequency</td>
<td>$f_s = 10$ MHz</td>
</tr>
<tr>
<td>Intermediate frequency</td>
<td>$f_{IF} = 0.42$ MHz</td>
</tr>
<tr>
<td>Sampling</td>
<td>Complex</td>
</tr>
</tbody>
</table>
Scenario: Highly dynamic- Velocity: 400 m/s- Acceleration: up to 15 g
Jerk: up to 50 g/s
Results (1/3)

Continuity

Doppler (Hz) - Channel 1

Doppler (Hz) - Channel 2

Doppler (Hz) - Channel 3

Doppler (Hz) - Channel 4
Results (2/3)

Speed and Accuracy

- Doppler (Hz) - Channel 1
- Doppler (Hz) - Channel 2
- Doppler (Hz) - Channel 3
- Doppler (Hz) - Channel 4

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Results (3/3)

Doppler Tracking Jitter (average)

Average Doppler jitter (Hz)

PLL 14 Hz
FLL/PLL 3/4 Hz
PLL 4 Hz
FFPLL

Channel #
Conclusions

- It is difficult to solve for dynamic robustness and noise rejection at the same time using classic PLL or FLL assisted PLL.

- Fuzzy systems can be used to replace the classic FLL assisted PLL noise filter and provide better dynamic performance and better noise rejection level.

- The proposed FFPLL performs as if it is a very narrow noise bandwidth PLL, in terms of noise level, and its dynamic performance is as fast as a wide PLL performance.

- Future work: Adaptive shaping of the input MFs to accommodate C/No variations due to signal interference.
Questions????
• **References**